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Flamespreading Processes in Ball Powder Propellants

Andrew L. Brant
Joseph W. Colburn
Carl R. Ruth
U.S. ARMY RESEARCH LABORATORY

Dennis W. Worthington
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Andrew L. Brant, Joseph W. Colburn, Carl R. Ruth, and Dennis W. Worthington*

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Ball powder propellants, loose and compacted, have been considered for use in recent years in tank and artillery applications. They are on interest due to the potential for high loading density, reduced temperature sensitivity, and improved performance through chemical/geometric progressivity control. However, there are several areas of concern, among them an uncontrolled deconsolidation process of compacted ball powder and a reduction in performance if the deterrent location is varied from the optimum.

In order to address these concerns, a study was conducted by the U.S. Army Ballistic Research Laboratory and Olin Corporation to investigate the initial phase of the ballistic cycle with a 120-mm simulator. The simulator, employing a disposable plexiglass chamber, allowed direct viewing of the events occurring during the ignition and flamespreading portion of the interior ballistic cycle via high-speed cinematography. Pressures were measured at the ends and interior of the chamber with gages mounted in the case base, projectile fins, and projectile base. Shots were conducted with loose and compacted ball powder charges at several temperatures.

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1. INTRODUCTION

For some time, the Olin Corporation's research and development facility at St. Marks, Florida, and the Ballistic Research Laboratory (BRL), Aberdeen Proving Ground, MD,* have been involved in an unfunded study investigating the potential of compacted BALL POWDER® propellants as a means of reducing propulsion system temperature sensitivity. Generally, as a propellant's temperature increases, chamber pressures and muzzle velocities increase, resulting in maximum performance only when firing at the hot temperature limit. Therefore, a desirable propellant should exhibit little change in burning characteristics over a wide temperature range (-45 to +65°C).

Olin has developed compacted BALL POWDER® charges in systems ranging from small caliber up to the 120-mm smooth bore tank gun that may partially meet this criterion. Their data, obtained using 20-mm and 30-mm compacted charges, indicated a substantial decrease in temperature sensitivity (Kruczynski 1991). As part of the unfunded research agreement with Olin and because of a lack of the necessary facilities at Olin to fire 120-mm compacted charges, the BRL undertook the investigation of the behavior of these charges in gun firings.

In the past, the BRL has extensively used large-caliber simulators to study the ignition and combustion processes of propellant charges (Chang and Rocchio 1988). Consequently, prior to the actual gun firings, a series of low-pressure simulator firings were undertaken to study the ignition and flamespread phenomena of both loose and compacted Olin charges. This report presents the results of these experiments.

2. EXPERIMENTAL APPARATUS AND CHARGE DESIGN

The apparatus designed to simulate a 120-mm round consisted of the case base of a real cartridge, a transparent acrylic tube containing propellant and an inert projectile, and the forcing cone section of a shortened gun barrel in which the front of the projectile was inserted. A cross-sectional view of the simulator is shown in Figure 1. The fixture was held together by a series of bolts and was mounted on a steel platform.

*On 30 September 1992, the U.S. Army Ballistic Research Laboratory (BRL) was deactivated and subsequently became part of the U.S. Army Research Laboratory (ARL) on 1 October 1992.

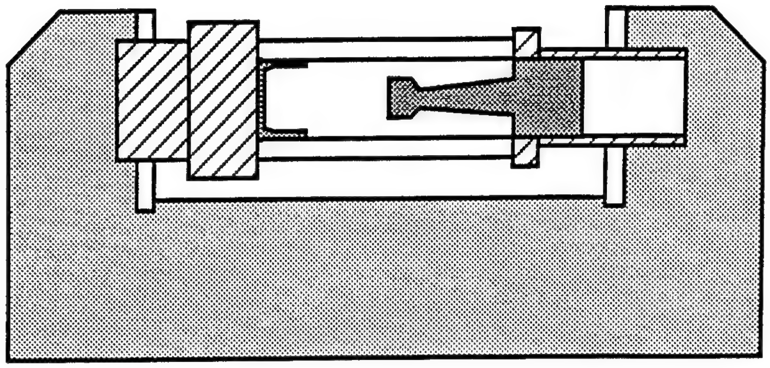


Figure 1. Diagram of Interior Ballistic Simulator

The simulator was generally capable of withstanding dynamic pressures up to approximately 15 MPa before rupturing. Pressure measurements were obtained using four PCB Model 113A23 gages. Two gages (P1,P2) were mounted in the breech, one gage (P3) was mounted in the rear of the fins, and one gage (P4) was mounted in the projectile afterbody near the front of the chamber. Photographic data was obtained at a framing rate of approximately 5,000 pictures per second using a 16-mm Hycam camera. A 35-GHz microwave interferometer was placed about 25 feet in front of the simulator to record projectile motion. The interferometer was protected from blast debris by a 1-inch-thick plexiglass shield and a steel trap designed to catch the projectile if it left the simulator. A schematic of the entire arrangement is shown in Figure 2.

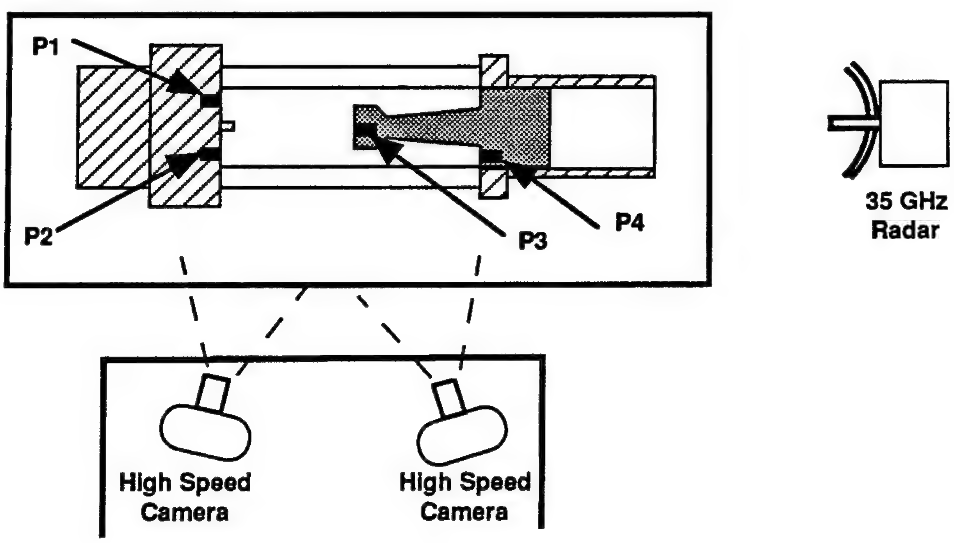


Figure 2. Experimental Test Setup

The propellant base grain for all the charges used was a deterred rolled BALL POWDER® propellant. Figure 3 shows a cross-sectional view of a sample grain along with plot of a typical deterrent gradient.

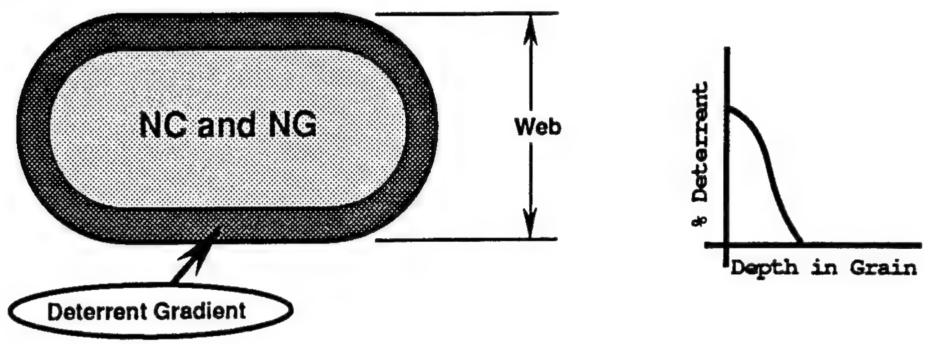


Figure 3. BALL POWDER® Propellant Base Grain.

A test was conducted with a loose BALL POWDER® propellant charge conditioned at 21°C. The charge consisted of 9.5 kg of loose BALL POWDER® propellant. The loading density was 0.97 g/cm³. The charge was ignited with a M129 primer. A cross-sectional view of the charge is shown in Figure 4.

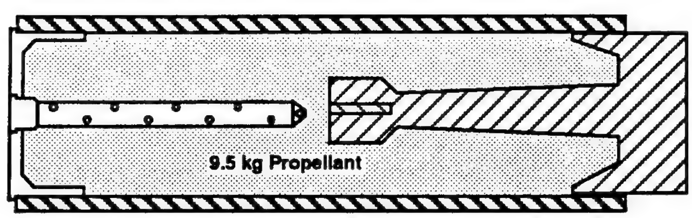


Figure 4. Loose BALL POWDER® Propellant Charge.

The compacted BALL POWDER® propelling charges were made up of several propellant segments. The compacted propellant segments were made by pressing the solvent-wetted propellant grains into shapes which would fit into a 120-mm cartridge case and provide adequate flamespreading throughout the charge. The compacted charge consisted of 9.3 kg of propellant arranged in an inner and outer cylinder with an annular space between them. There was also a small vertical gap between each of the propellant segments. The loading density was 0.95 g/cm³. The charge was ignited with a XM123 primer and a 100-g black powder basepad igniter. A cross-sectional view of the charge and propellant segments is shown in Figure 5. Compacted propellant charges were tested at -32°C, 21°C, and 49°C.

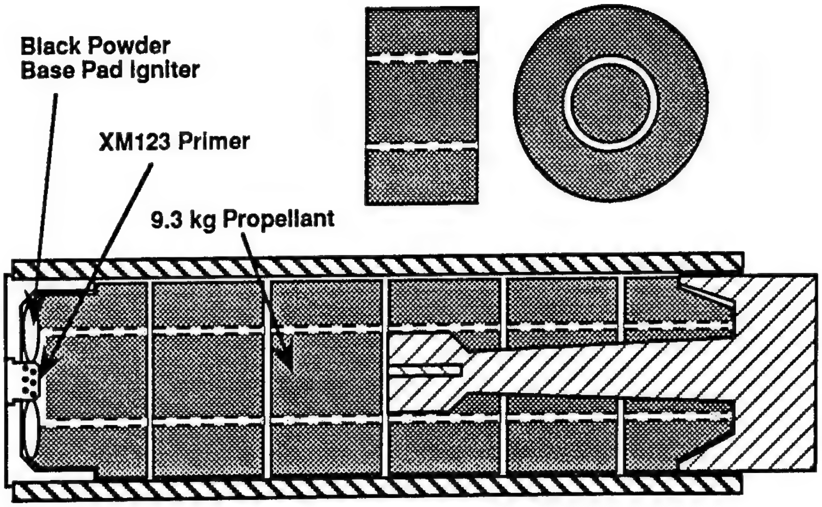
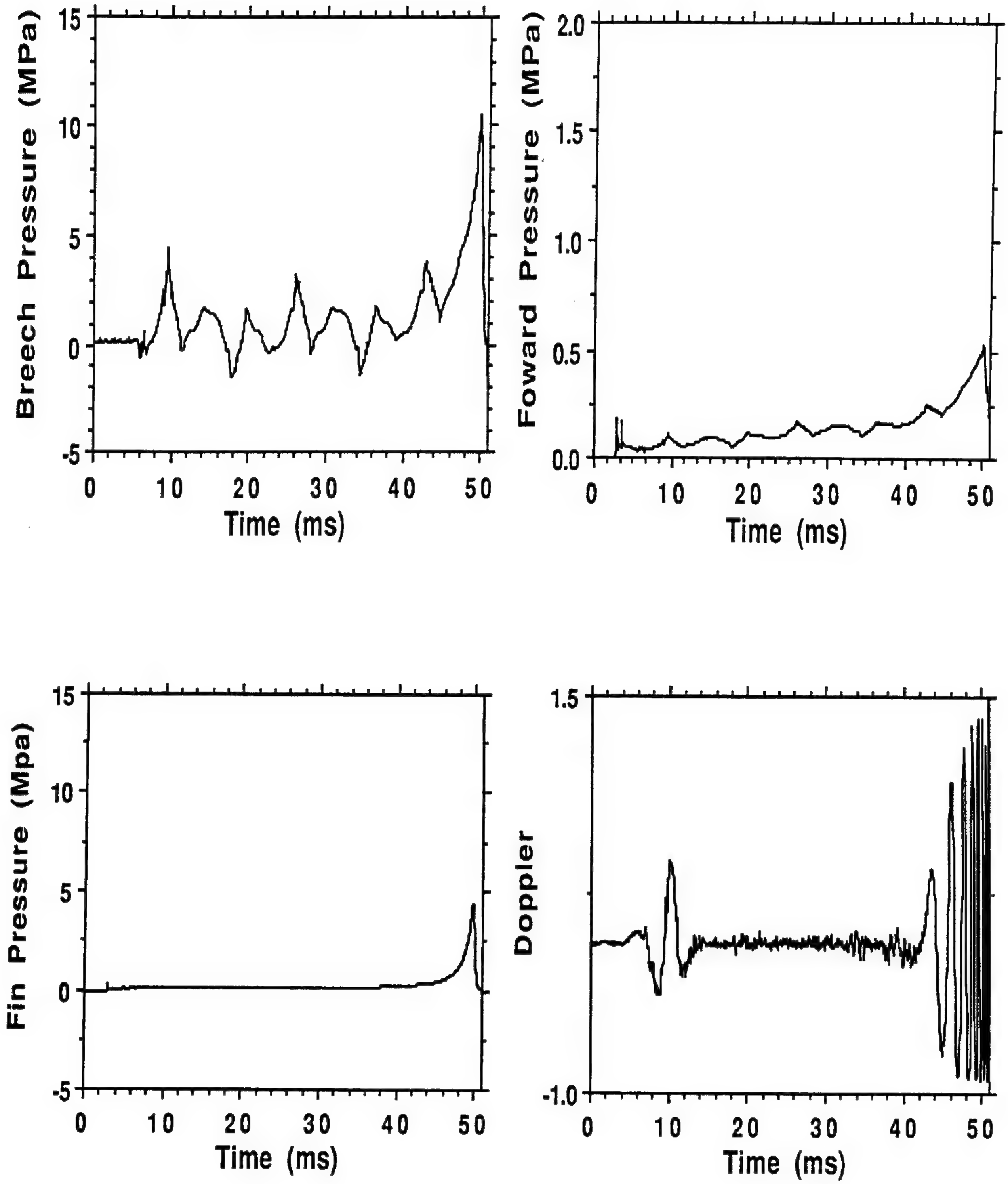


Figure 5. Compacted BALL POWDER® Propellant Charge.

3. EXPERIMENTAL RESULTS

3.1 Loose BALL POWDER® Charge, 21°C. The pressure-time and displacement-time histories for the loose BALL POWDER® charge are presented in Figure 6. This charge showed a peak pressure of 10.9 MPa at gage locations P1 and P2, 4.9 MPa at P3, and 0.51 MPa at P4. The oscillations on the pressure-time traces are believed to be caused by various modes of 60 cycle noise. The radar showed projectile motion between 8 and 10 ms, then the projectile stopped and remained stationary until 42 ms. A schematic of the events taking place during the flamespread is shown is Figure 7. At approximately 8 ms, the propellant bed is seen moving forward and impacting the projectile. At 15 ms, the formation of dark areas in the rear quarter of the charge was noted. These areas appeared in a pattern corresponding to that of the vent holes in the primer. These dark areas, which are believed to be combustion products, continued to enlarge. At 32 ms, the first area of flame was seen near the center of one of the dark areas, which is shown in black on the schematic diagram. Other small areas of flames appeared in the other dark areas as time progressed. At 50 ms, there were three areas of flame in the rear of the charge just before the chamber burst.



Fiqure 6. Pressures and Radar Data, Loose BALL POWDER , 21°C.

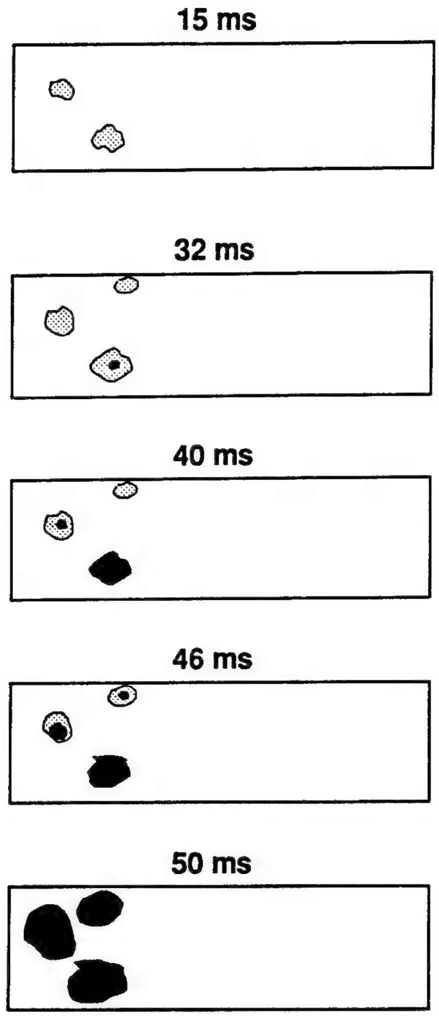
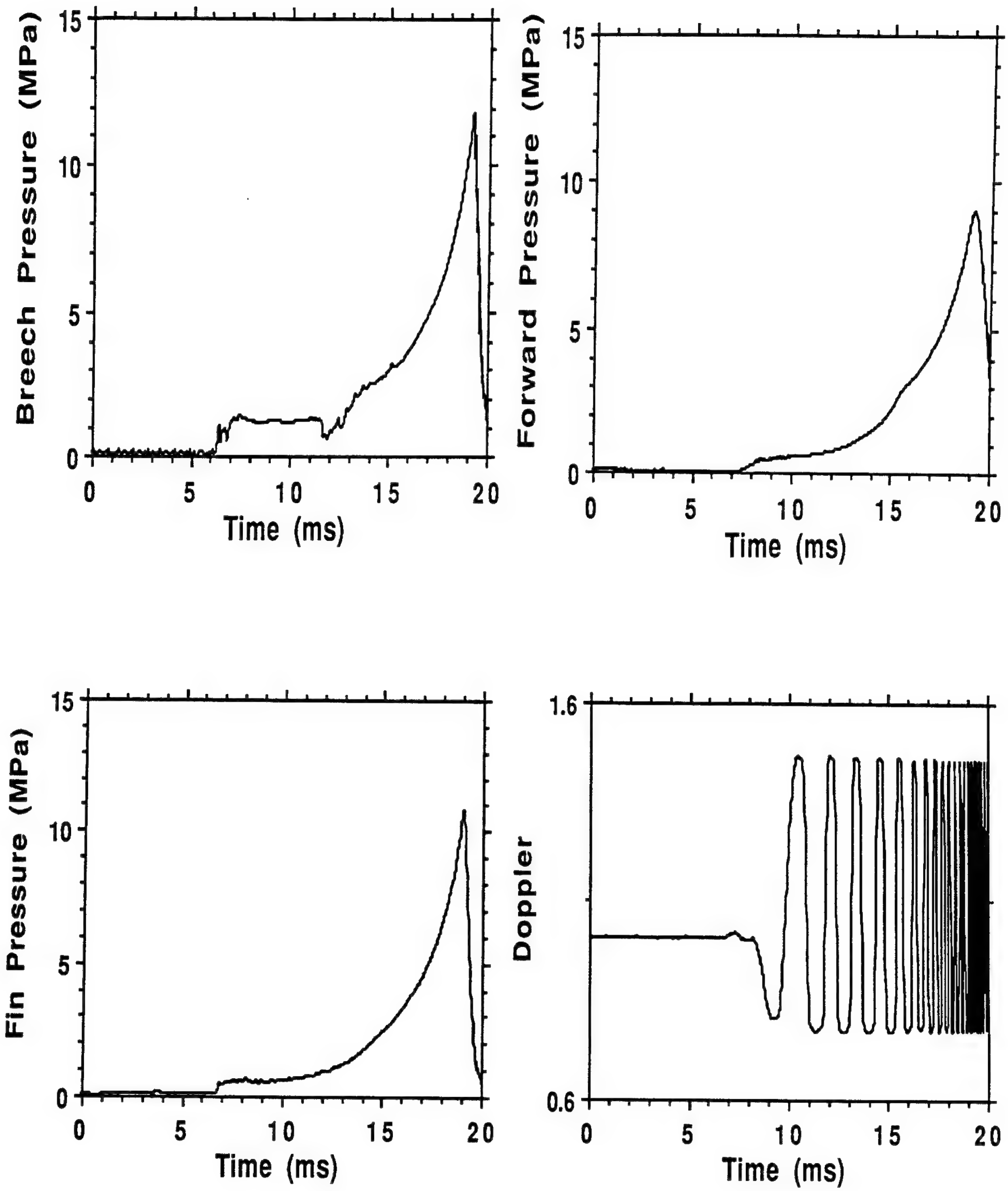


Figure 7. Schematic of Flamespread in Loose BALL POWDER®, 21°C.

3.2 Compacted BALL POWDER® Charge, 21°C. A compacted BALL POWDER® charge was conditioned at 21°C. The pressure-time and displacement-time plots are shown in Figure 8. The round obtained a peak pressure of 11.9 MPa at the breech (P1 and P2), 11.0 MPa at the fins (P3), and 9.2 MPa at the forward end of the chamber (P4). The projectile started to move at approximately 8 ms and accelerated smoothly until the chamber burst. A schematic of the events taking place is shown in Figure 9. At 1 ms, the XM123 primer had ignited the basepad and luminous gases could be seen near the rear of the charge. At 1.5 ms, the luminous gases advanced around the rear two segments and also through the inside of the charge to the forward end of the chamber. The luminous gases continued to spread throughout the charge.



Fiqure 8. Pressures and Radar Data, Compacted BALL POWDER , 21°C.

At 13.5 ms, the rear of the charge became bright orange, indicating propellant ignition. At 19 ms, the propellant in the center of the charge, as seen through the vertical gaps, became bright orange which indicated propellant ignition at that location.

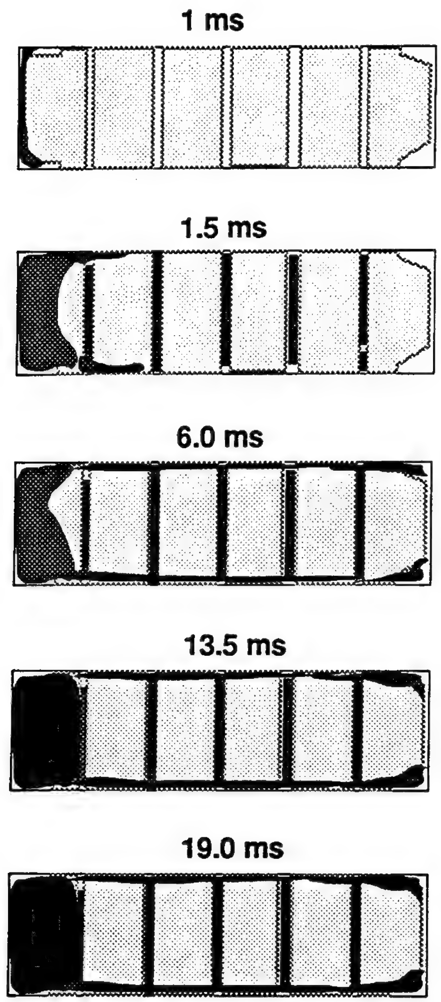
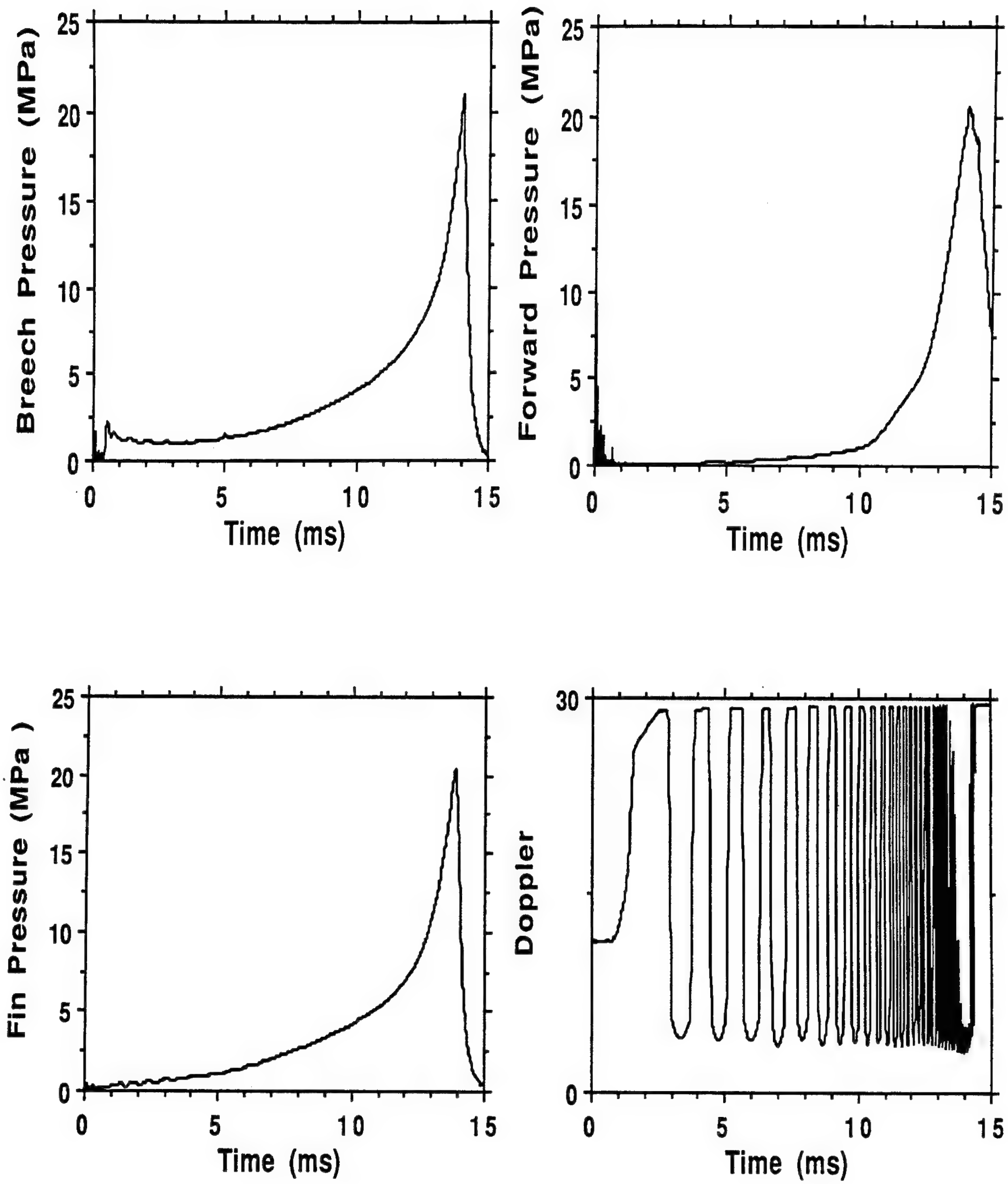


Figure 9. Schematic of Flamespread in Compacted BALL POWDER®, 21°C.

3.3 Compacted BALL POWDER® Charge, -32°C. A compacted BALL POWDER® charge was conditioned at -32°C for use in the ballistic simulator. The pressure-time and displacement-time plots are shown is Figure 10. The round reached a peak pressure of 22.5 MPa at the breech (P1 and P2), 22.0 MPa at the fins (P3), and 21.5 MPa at the forward end of the chamber (P4). Projectile motion started at 1 ms and accelerated smoothly until the chamber burst. A schematic of the events



Fiqure 10. Pressures and Radar Data, Compacted BALL POWDER , -32°C.

taking place is shown in Figure 11. Between 12 and 14 ms the rear half of the charge showed bright, erratic flames, which indicated the propellant was deconsolidating. At 14 ms the chamber burst.

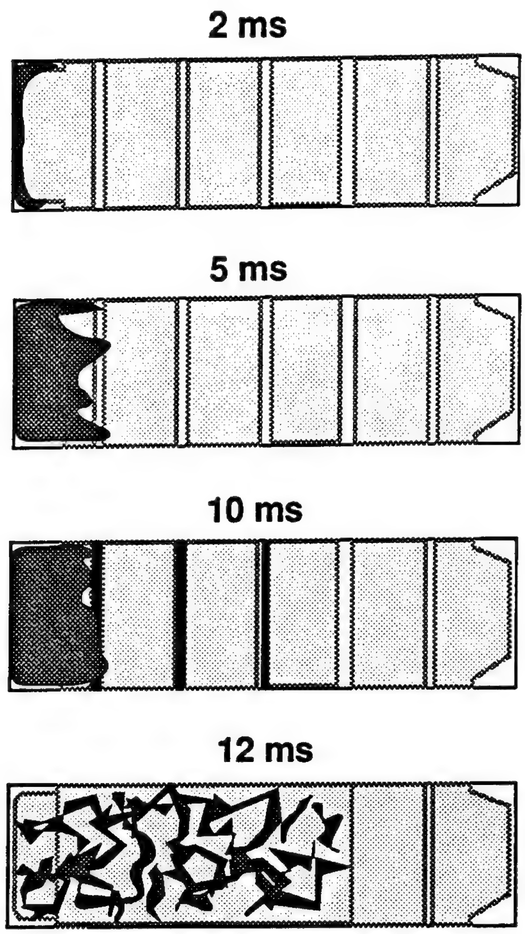
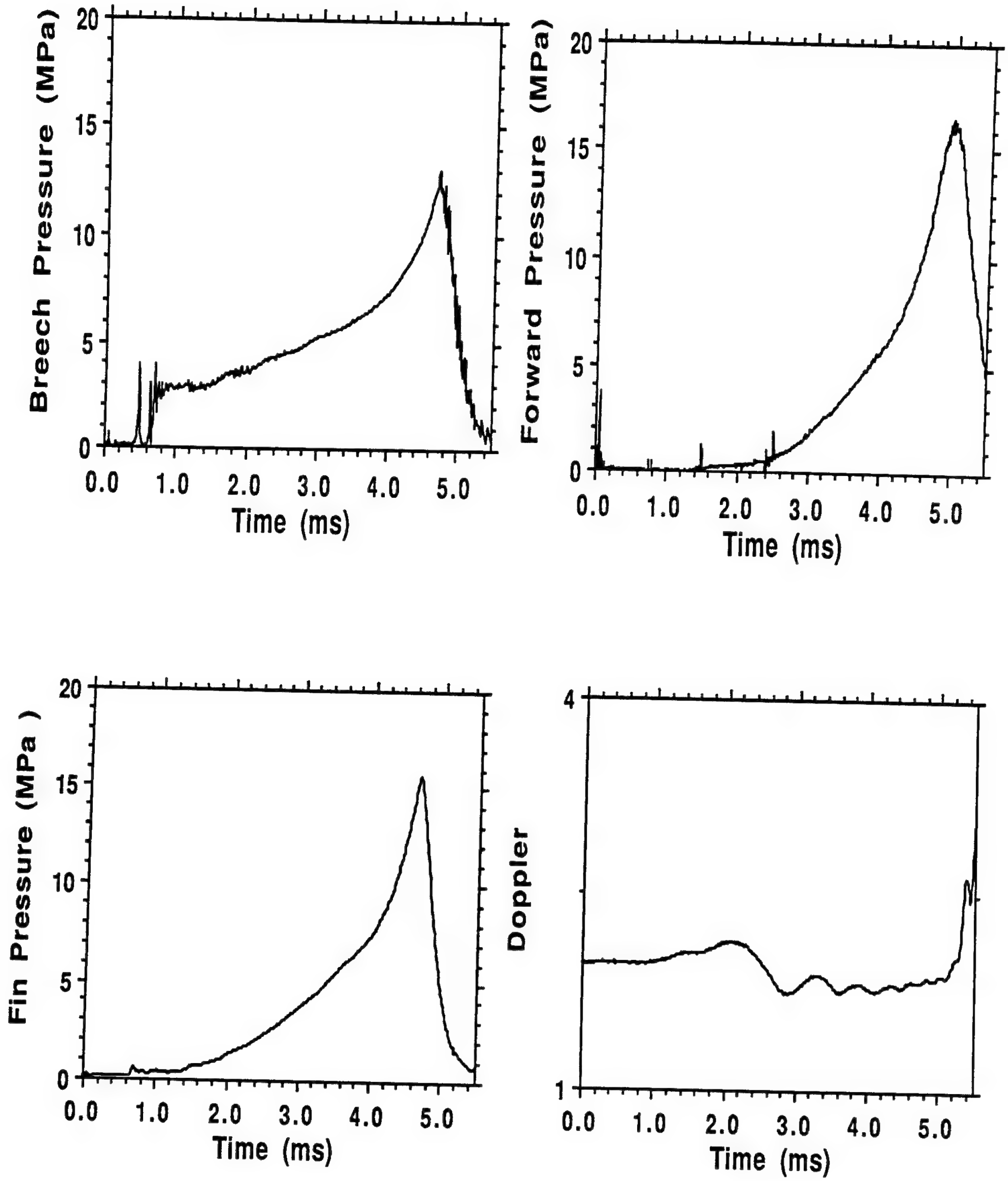


Figure 11. Schematic of Flamespread in Compacted BALL POWDER®, -32°C.

3.4 Compacted BALL POWDER® Charge, 54°C. A compacted BALL POWDER® charge was conditioned at 54°C. The pressure-time and displacement-time plots are shown is Figure 12. The round reached a peak pressure of 13.1 MPa at the breech (P1 and P2), 15.6 MPa at the fins (P3), and 16.4 MPa at the forward end of the chamber (P4). Projectile motion started at approximately 2 ms and accelerated smoothly until the chamber burst. A schematic of the events taking place is shown in Figure 13. At 1 ms, the XM123 primer had ignited the blackpowder basepad and luminous gases could be seen around the rear of the charge. By 3 ms, luminous gases could be seen in the vertical gaps between the segments in the rear half of the charge as well as



Fiqure 12. Pressures and Radar Data, Compacted BALL POWDER , 54°C.

in the forward end of the chamber. At 4 ms, the rear section of the charge became bright orange which indicated the propellant had started to ignite. The chamber burst at 4.5 ms.

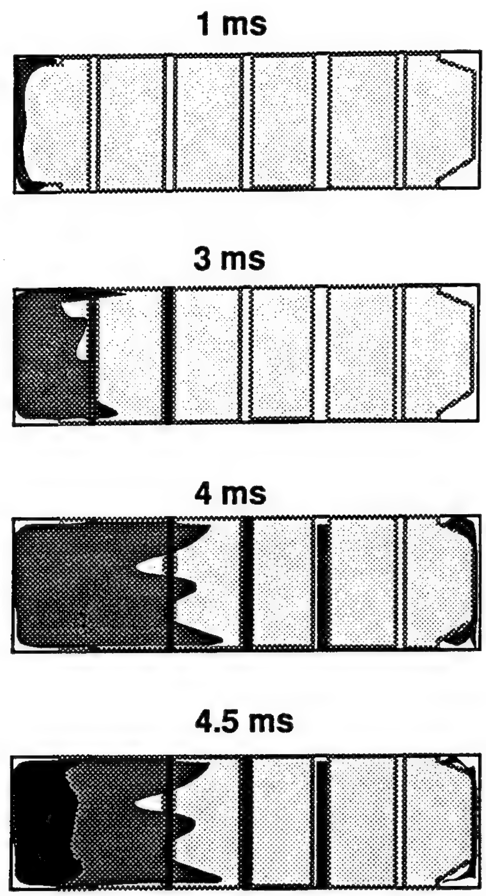


Figure 13. Schematic of Flamespread in Compacted BALL POWDER®, 54°C.

4. CONCLUDING REMARKS

The testing conducted with loose BALL POWDER® propellants showed a very high resistance to the flow of igniter products. This high resistance led to poor flamespread and localized ignition in the base of the charge.

Due to the axial ports, the compacted propellants showed rapid propagation of igniter products to all areas of the chamber, which led to uniform ignition of the charge. The flow could be further enhanced by altering the shapes and sizes of the propellant segments.

Deconsolidation of the compacted propellant was seen only with the charge conditioned at -32°C. The key to temperature sensitivity reduction is progressively more deconsolidation as the temperature of the charge is reduced. Such deconsolidation took pace at -32°C; we may not have observed it at 21°C due to earlier simulator chamber failure.

Based on the results obtained during the simulator tests, a series of gun firings is planned in the 120-mm gun with compacted BALL POWDER® propellants conditioned to temperatures spanning the required operational spectrum. The goal is to demonstrate a significantly reduced temperature sensitivity across this range compared to conventional charges.

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